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...nical Rep... ...eries on the
...al Ecosyst... Atmosphere Study (BOREAS)

...t G. Hall and Jaime Nickeson, Editors

...ume 43

...OREAS RSS-2 Level 1B ASAS
...-Sensor Radiance

...ussell, P. Dabney, W. Kovalick, D. Graham, M. Bur, J. Irons, and M. Tierney

...nal Aeronautics and
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Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Jaime Nickeson, Editors

Volume 43

BOREAS RSS-2 Level 1B ASAS Image Data: At-Sensor Radiance in BSQ Format

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BOREAS RSS-2 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format

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Summary

The BOREAS RSS-2 team used the ASAS instrument, mounted on the NASA C-130 aircraft, to create at-sensor radiance images of various sites as a function of spectral wavelength, view geometry (combinations of view zenith angle, view azimuth angle, solar zenith angle, and solar azimuth angle), and altitude. The level-1b ASAS images of the BOREAS study areas were collected from April to September 1994 and March to July 1996.

Note that only a sample of the Level-1b ASAS images are contained on the BOREAS CD-ROM set. The sample files contain data collected on 04-August-1994 over the NSA-OBS site. Some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See section 8.2 for details.

In addition to the sample image files, an inventory file is supplied on the CD-ROM to inform users about all the data that were collected. See Sections 15 and 16 for information about how to acquire the data not contained on the CD-ROM set.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-02 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format

1.2 Data Set Introduction

The level-1b Advanced Solid-state Array Spectroradiometer (ASAS) data set consists of a series of 62-band images in each site pass, where a site pass is one flight over a given target area. Each site pass consists of up to 8 images, one at each of 8 look angles. The ASAS images were acquired from

19-APR-1994 to 17-SEP-1994, during the BOREAS field campaigns.

1.3 Objective/Purpose

The objectives were to collect multispectral, multiangle data during several field campaigns for a variety of purposes: develop capabilities to remotely monitor the state of the snow pack in the boreal forest; study the bidirectional reflectance properties of snow and boreal forest canopies with a snow background; obtain bidirectional reflectance data for the early growing season; study the bidirectional reflectance properties of boreal forest canopies, including phenological variations; and simulate Multiangle Imaging SpectroRadiometer (MISR) data by acquiring data at or close to MISR view zenith angles.

1.4 Summary of Parameters

The ASAS measures at-sensor radiance of surfaces as a function of spectral wavelength, view geometry (combinations of view zenith angle, view azimuth angle, solar zenith angle, and solar azimuth angle), and altitude.

1.5 Discussion

The main objectives of the BOReal Ecosystem-Atmosphere Study (BOREAS) conducted in Manitoba and Saskatchewan throughout 1994 and 1996 are to improve process models that describe the exchanges of energy, water, carbon, and trace constituents between the boreal forest and the atmosphere, and to develop methods for applying the process models over large spatial scales using remote sensing and other integrative modeling techniques. The Remote Sensing Science (RSS) group, of which ASAS is a part, is responsible for developing linkages between optical and microwave remote sensing and boreal zone biophysical parameters at various scales (leaf, canopy, and regional) using measurements from field, aircraft and satellite sensors plus a range of radiative transfer models.

The experiment strategy for ASAS was to image the flux tower sites during each of the various field campaigns. ASAS obtained coordinated measurements with the Portable Apparatus for the Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA) (on the ground) and other remote sensing instruments (Compact Airborne Spectrographic Imager (CASI), Airborne Visible-Infrared Imaging Spectrometer (AVIRIS), Moderate Resolution Imaging Spectroradiometer (MODIS) Airborne Simulator (MAS), and Polarization and Directionality of Earth's Reflectances (POLDER)) when and where possible. For each site, three sets of multiangle data were collected by flying three flight lines in view azimuths that were parallel, perpendicular, and oblique to the solar principal plane. View zenith angles corresponding to MISR angles were obtained for a number of data sets.

1.6 Related Data Sets

BOREAS RSS-01 PARABOLA Surface Reflectance and Transmittance Data
BOREAS RSS-02 ASAS Extracted Multi-angle Spectral Reflectance Factors
BOREAS RSS-03 Helicopter-Mounted MMR Reflectance Data
BOREAS RSS-03 Helicopter-Mounted SE-590 Reflectance Data
BOREAS RSS-11 Ground Network of Sun Photometer Measurements
BOREAS RSS-12 Automated Ground Sun Photometer Measurements in the SSA
BOREAS RSS-18 Level-1b AVIRIS Imagery: At-sensor Radiance in BIL Format
BOREAS RSS-19 1994 CASI At-sensor Radiance and Reflectance Images
BOREAS RSS-19 1996 CASI At-sensor Radiance and Reflectance Images
BOREAS RSS-20 POLDER C-130 Measurements of Surface BRDF

2. Investigator(s)

2.1 Investigator(s) Name and Title
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2.2 Title of Investigation
Terrestrial Ecosystem Studies of the Boreal Forest Using Bidirectional Reflectances Acquired by a Multispectral, Multiangle Imaging Spectroradiometer

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ASAS information via the World Wide Web is available at http://asas.gsfc.nasa.gov/.

3. Theory of Measurements

ASAS is an airborne imaging spectroradiometer that was modified by National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) to point off-nadir for the purpose of remotely observing directional anisotropy of solar radiance reflected from terrestrial surfaces. The instrument is capable of off-nadir pointing from approximately 70° forward to 55° aft along-track (in the direction of flight). As the aircraft passes over the ground target, digital radiance measurements of the target are recorded for a discrete sequence of fore-to-aft view zenith angles within this range.

The terms "tilt," "look," "point," or "view" angles generally are used interchangeably when referring to the ASAS view zenith angles; however, the actual view zenith angle may vary from the angle at which the sensor is pointed due to an across-track angular component to the view zenith angle. This across-track angular component is largest at a nadir-pointing angle, and relatively insignificant at far off-nadir pointing angles. For the BOREAS data collection flights, ASAS imaged most study sites at eight different tilt angles: +70°, +60°, +45°, +26°, nadir, -26°, -45°, and -55°. Areas in the imagery nearest the center detectors will have view zenith angles the same as the tilt angle, but areas at the edges of the array (far left and far right of a line) may have a different view zenith angle. The variation by tilt angle is given below:

TILT_ANGLE (fore and/or aft)	VIEW_ZEN_ANGLE (image center)	VIEW_ZEN_ANGLE (image edges)
70°	70.0°	70.2°
60°	60.0°	60.4°
55°	55.0°	55.5°
45°	45.0°	45.7°
26°	26.0°	27.5°
00°	0.0°	9.4°

For the Focused Field Campaign - Thaw (FFC-T) data sets, two additional view angles at +15° and -15° were also acquired. Imaging of sites in the 70° off-nadir view angle is problematic, and this particular angle may or may not be available in every data set. Data were acquired in 62 spectral bands ranging from 404 - 1023 nanometers (nm) with a spectral resolution of approximately 10 nm in each band.

4. Equipment

4.1 Sensor/Instrument Description

The ASAS instrument employs a cooled 1024 x 1024 element silicon charge-coupled device (CCD) detector array to generate multispectral digital image data in a push-broom mode. The first 324 rows of the CCD are masked. The next 186 rows are exposed to the output from the spectrometer. The final 516 rows are masked and used for readout of the array. Two of the rows under the mask collect smear data that are used to remove smear effects and dark current from the data.

During the BOREAS missions, the operating method of the array was to bin every 3 rows into one spectral band, which resulted in 62 spectral channels. In addition, every 2 detectors within each row were binned resulting in 512 pixels (per row or line) in the output image data. In this configuration, the spectral band centers, which range from 404 to 1023 nm, are spaced at approximately 10 nm. Each spectral band has a full-width-at-half-maximum (FWHM) of approximately 10 nm.

4.1.1 Collection Environment

The ASAS instrument is mounted on the underside of the platform aircraft fuselage with the sensor optics either slightly protruding into the slipstream or retracted into the fuselage pressure box, depending on the view angle. As the aircraft approaches the target site from a distance, the ASAS instrument is pointed forward-looking. A video camera bore-sighted with the ASAS optical head relays a picture to an onboard monitor screen at the ASAS operators' station. This enables the operator to identify the site and continue tracking it through a sequence of view angles as the aircraft proceeds on a flight line over the site. When the site comes into view on the forward point, the operator begins the data acquisition. The sequence is timed such that the view is at nadir when the aircraft is directly over the site, and aft-looking views are taken after passing the site. Determining which views are forwardscatter or backscatter requires examination of the aircraft heading and the solar azimuth angle, given in the ASAS header.

During the 1994 BOREAS missions data were acquired as follows: Flux Towers - view azimuths parallel, perpendicular and oblique to the solar principal plane; multiple view zenith angles. Transect or Modeling Sub-Area Mapping Grids - nadir view zenith angle. In 1996, data over flux towers were acquired in view azimuths parallel, oblique, and occasionally perpendicular to the solar principal plane.

During transect runs between the Northern Study Area (NSA) and Southern Study Area (SSA), data were recorded at a nadir view zenith angle.

As the platform aircraft flies forward, each row of 512 detector bins is electronically scanned to generate 62 spectral channels of digital image data in a push-broom mode. The signals generated by the CCD detectors are sampled at a rate of 38 frame lines per second to produce the along-track dimension of the imagery (image lines). The sampled signal from each detector is digitized to 12 bits and the digital data are stored on a high-density S-VHS format tape using a buffered Very Large Data Storage (VLDS) data recorder.

4.1.2 Source/Platform

- 1994 flights: NASA Ames Research Center (ARC) C-130B Earth Resources Aircraft.
- 1996 flights: NASA Wallops Flight Facility (WFF) C-130Q Aircraft.

4.1.3 Source/Platform Mission Objectives

Mission objectives were to collect multispectral, multiangle bidirectional reflectance data (acquired as at-sensor radiances) over flux tower sites for study of boreal forest canopies and simulation of MISR data by obtaining measurements at MISR view angles. Nadir multispectral data were acquired over the modeling sub-areas in each study area (1994 only) and on transects between the SSA and NSA. Multispectral, multiangle data were also collected over a calibration target in the SSA and several other occasional targets of opportunity (see Sections 7.1.1 and 7.2.1).

4.1.4 Key Variables

ASAS measures at-sensor spectral radiance in the visible and near-infrared portion of the spectrum as a function of view geometry.

4.1.5 Principles of Operation

The ASAS optical head is mounted in an open port in the underside of the C-130 aircraft. A complex pointing mechanism incorporating a gimbal enables the sensor to view off-nadir, facilitating movement in the horizontal, vertical, fore, aft, and yaw directions.

As the aircraft approaches the target site from a distance, the ASAS instrument is pointed forward-looking. A video camera mounted adjacent to the ASAS optical head relays a picture to an on-board monitor screen at the ASAS operator's station. This enables the operator to identify the site and continue tracking it through a sequence of view angles as the aircraft proceeds on a flight line over the site. When the site comes into view on the first forward angle, the operator initiates the data acquisition process. The sequence is timed such that the view is at nadir when the aircraft is directly over the site, and aft-looking views are taken after passing the site.

Yaw compensation can be performed by the operator (if necessary) to prevent the site from drifting out of the field of view.

As the platform aircraft flies forward, each row of 1024 (spatial dimension) x 186 (spectral dimension) array elements is electronically scanned. Every 2 elements in the spatial dimension and every 3 elements in the spectral dimension are binned, which generates digital image data for 512 spatial pixels in 62 spectral channels. The signals generated by the CCD detectors are sampled at a rate of 38 frame lines per second to produce the along-track dimension of the imagery (image lines) in push-broom mode. The sampled signal from each detector is digitized to 12 bits and the digital data are stored on a high-density S-VHS format tape using a buffered VLDS data recorder.

4.1.6 Sensor/Instrument Measurement Geometry

Radiation incident on the ASAS aperture is focused onto an entrance slit by an f/1.4 objective lens with a 57.2 millimeters (mm) focal length. The entrance slit is 50 micrometers (μm) wide across-track, and 23 μm wide along-track. The lens focuses incoming energy through the entrance slit into a 1:1 optical relay with an effective focal length of 76.3 mm in each half. In each half of the optical relay, a 90°-mirror prism folds the optical path to create a compact optical head. A transmission grating ruled at 75 lines per mm and blazed at 530 nanometers (nm) is located between the two prisms to disperse the radiant energy into its wavelength spectrum, which is in turn directed by the second prism onto the 186 rows of the array in the focal plane, where the CCD was mounted.

The instantaneous field-of-view (IFOV) of an ASAS pixel is a function of optics, detector dimensions, tilt angle (view angle), and aircraft altitude and attitude (pitch and roll). The optical system includes an f/1.4 objective lens with a 57.2 mm focal length, providing a 0.33 radian (19.3°) total angular across-track field-of-view. The individual angular resolution of the center detectors is 0.66 mrad across-track. The along-track field-of-view is 0.44 mrad.

Each detector has dimensions of 19.0 µm spatially (across-track) and 19.0 µm spectrally; however, with a binning factor of 2 in the spatial dimension and 3 in the spectral dimension, the resulting array pixel size is 38.0 µm in the spatial dimension and 57 µm in the spectral dimension.

See Section 7.1.3 for spatial resolution.

4.1.7 Manufacturer of Sensor/Instrument

The ASAS instrument evolved over a number of years. The original optics, built by TRW, were part of the Scanning Imaging Spectroradiometer (SIS) constructed in the early 1970's for NASA's Johnson Space Center (JSC). ASAS was created in 1981 when a charge-injection device (CID) silicon detector array, made by GE, was incorporated with the optical system for a joint program involving NASA JSC and the Naval Ocean Systems Center. In 1984, the sensor was transferred to NASA GSFC, where the aircraft-mounting bracket was modified for off-nadir pointing.

In late 1991, the pointing mechanism was upgraded by NASA GSFC to allow view angles of 70° forward to 55° aft, and to enable operator-controlled aircraft yaw compensation. In 1992, the CID was replaced with a Thomson CSF Model TH7896A (high-speed version) CCD silicon detector array. BOREAS data were acquired with this CCD array.

4.2 Calibration

Radiometric calibration data for the BOREAS experiment were acquired from two primary calibration sources: 1) a 1.2 m diameter integrating hemisphere in the NASA GSFC calibration laboratory, and 2) a 30 inch diameter (0.76 m) portable hemisphere that is owned and operated by GSFC. The latter source was used for in situ calibration data acquisition since it could be positioned directly under the aircraft-mounted instrument. The integrating hemisphere is operated and maintained by the Sensor Development and Characterization Branch at NASA GSFC. Up to 12 levels of radiance can be provided for calibration by turning the internal tungsten filament lamps on or off. The hemisphere is calibrated on an absolute scale by comparison to the output from a National Institute of Standards and Technology traceable calibration lamp using a laboratory-based transfer spectroradiometer. In a calibration run, ASAS is exposed to a 12-level sequence of spectral radiance levels from the hemisphere. Dark current (the response of the instrument under conditions of no incident radiation) is also acquired.

The portable hemisphere can provide up to six different radiance levels in addition to dark current; however, during the BOREAS field campaigns of 1994, only three levels provided by three 30 Watt tungsten lamps were operating. For calibration of the portable hemisphere, users should contact Brian Markham or John Schafer of NASA GSFC.

The digitized response of each detector bin was recorded for each calibration source intensity level by selectively controlling the number of lamps turned on. When possible, data were acquired with the instrument or the portable hemisphere positioned at two different orientations, opposed by 180°, to account for any nonuniformity in the reflective surface of the hemisphere. In some instances, four different orientations, opposed by 90°, were used. Calibration data were acquired for each optical filter combination (at least four) used by ASAS during the BOREAS field campaigns.

The digital responses of each detector bin to the multiple hemisphere radiance levels were used to derive a linear radiometric response function for each detector bin. To begin, an offset value was subtracted from each digital response. The offset was a weighted average of the digital counts from two masked detector bins located at the beginning and end of each illuminated column of detectors in the array. The weighting was a function of the relative proximity of each illuminated detector bin to each masked detector bin along a detector column. The offset subtraction removes dark current signal and "contamination" from the signal readout process from each digital response. A mean offset-corrected digital response to each radiance level was then calculated for each detector bin.

Least-squares regression was used next to express digital response as a linear function of radiance for each detector bin. Note that an individual regression line was derived for each of the 31,744 illuminated detector bins. The slope of each regression line provided the radiometric gain (i.e., digital counts per unit radiance) for each detector bin. Along each row of 512 detector bins per spectral band, the gains peak at the center bin and decrease with distance from the center due to optical vignetting.

The radiometric correction applied to ASAS data acquired in flight removes the digital response variation due to bin-to-bin gain variation along a spectral row of 512 detector bins. A mean gain value was first calculated for each of the 62 rows of detector bins (i.e., for each spectral band). We refer to the mean gain as the radiometric resolution factor. A list of radiometric resolution factors for each spectral band, in units of digital counts per mW/(cm^2 * sr * µm), can be found in the fourth column of the table in the American Standard Code for Information Interchange (ASCII) header record of each ASAS site pass (see section 8.2). The radiometric resolution factors can vary between data acquisition dates depending on the fore-optic filter combination employed at the time of acquisition.

The radiometric correction process scales each digital count generated in flight by each detector bin to the mean gain for the bin's spectral band. An offset is first subtracted from each datum and then the offset-corrected datum is divided the individual gain for the associated detector bin. These two steps produce a data value in units of radiance. The radiance value is then multiplied by the mean gain for the associated spectral band to return the value to units of digital counts. The scaled digital count is saved as an integer value in the radiometrically corrected digital image product. The process is performed using floating-point arithmetic until the final step, where floating-point values are truncated to integer digital counts. Saving the data as scaled integer values reduces the volume of the radiometrically corrected digital images and precludes the expression of false radiometric resolution in the corrected values.

An investigator analyzing radiometrically corrected ASAS data may convert the digital counts to units of radiance by simply dividing the digital counts by the radiometric resolution factor provided for the associated spectral band as provided in the ASCII header record. The result will be a value in units of mW/(cm^2 * sr * µm). To covert this value to W/(m^2 * sr * µm), multiply by 10.

Signal-to-noise (S/N) ratios are also measured from the radiometric calibration data. Equations are derived that provide the S/N ratio as a function of digital count. These equations are basically second-order (used for 1994 data) or third-order (used for 1996 data) polynomials that characterize progressively higher S/N ratios with increasing digital count (until a maximum level is reached). A maximum S/N ratio of approximately 600 was obtained from the calibration data acquired for the BOREAS project.

The appropriate S/N equation is stored in the ASCII header of each ASAS image. The header also contains information on how to apply the equation to either the digital counts (before the radiometric resolution factors are applied) or to the radiances (after the factors are applied) in each channel. The S/N ratios did not vary greatly over the course of the BOREAS field seasons. Some example S/N equations applicable to the BOREAS ASAS data can be seen in the SAMPLE header given in Section 8.4.

Spectral Calibration

A McPherson Model 285 0.5 m double monochromator serves as the spectral reference source for ASAS. Light from the monochromator is collimated by a parabolic mirror and directed to the ASAS optics. Instrument output is sampled every 0.5 nm. The band centers have been computed by determining the centroid of the area under the response curve for each band. FWHMs were measured directly from the response curves.

4.2.1 Specifications

ASAS spectral band centers and FWHMs applicable to 1994 and 1996 BOREAS data sets are as follows:

Band	Center (nm)	FWHM (nm)	Band	Center (nm)	FWHM (nm)
1	404.3	9.5	32	711.9	11.0
2	413.7	9.5	33	722.1	11.0
3	423.2	9.5	34	732.3	11.0
4	432.4	10.0	35	742.6	11.0
5	441.7	10.0	36	752.9	11.0
6	451.4	10.0	37	763.2	11.0
7	460.9	10.0	38	773.5	11.0
8	470.5	10.0	39	783.8	11.5
9	480.3	10.5	40	794.1	11.0
10	490.2	10.5	41	804.5	11.0
11	500.0	10.0	42	814.9	11.0
12	509.7	10.5	43	825.3	11.5
13	519.6	10.0	44	835.7	11.0
14	529.7	10.5	45	846.0	11.0
15	539.9	10.5	46	856.4	11.0
16	549.8	10.5	47	866.8	11.0
17	559.6	10.0	48	877.2	11.5
18	569.4	10.5	49	887.6	11.5
19	579.4	10.5	50	897.9	11.0
20	589.7	11.0	51	908.3	11.0
21	600.0	10.5	52	918.7	11.0
22	610.2	11.0	53	929.0	11.0
23	620.3	10.5	54	939.5	10.5
24	630.4	10.5	55	949.9	11.0
25	640.7	11.0	56	960.3	11.0
26	650.9	10.5	57	970.7	11.0
27	661.1	11.0	58	981.1	11.0
28	671.4	10.5	59	991.5	10.5
29	681.5	11.0	60	1001.9	10.5
30	691.6	11.0	61	1012.2	10.5
31	701.7	11.0	62	1022.7	10.5

4.2.1.1 Tolerance

Individual radiometric resolution factors for each spectral band were adopted in 1989 to account for the variation of silicon detector response as a function of wavelength. With every detector bin individually calibrated, each has its own gain, and as a result, its own specific resolution. A mean resolution (the radiometric resolution factor) is determined for each channel, to which all 512 detector bins within each channel are scaled. This results in very slight radiometric over-resolution of pixels furthest away from the center, while pixels proximal to the center are slightly under-resolved radiometrically.

Periodic horizontal striping of low brightness is apparent in some of the ASAS imagery acquired for BOREAS. This artifact was caused by an internal array timing problem that resulted in shortened integration times (and lower signal levels) for some data frames. Efforts have been made to identify and correct these "low energy" frames but striping may occasionally be visible in some images, usually at a frequency of every 6-7 lines (1994 Intensive Field Campaigns (IFCs) 1-3). For data sets collected over the SSA during the 1994 FFC-T, the frequency is approximately 29 to 30 lines. This problem was corrected before the 1996 field seasons.

4.2.2 Frequency of Calibration

In general, ASAS acquires radiometric calibration data at least twice for each mission, with one calibration set acquired prior to the mission, followed by a postmission calibration after the instrument arrives back at GSFC. Radiometric calibration data were also acquired during some 1994 BOREAS field campaigns using the portable integrating hemisphere described elsewhere in this document. In 1996, the portable hemisphere was used only in the winter field campaign. After several months of quality control and related analyses, it was determined that calibration data acquired on the following dates would be used to generate the gains for calibration of data acquired during the listed field campaigns:

Acquisition Date	Applicable BOREAS Field Data
01-JUN-94	1994 FFC-Thaw, IFC-1 data
02-AUG-94	1994 IFC-2 data
17-SEP-94	1994 IFC-3 data
05-APR-96	1996 data

Laboratory spectral calibrations of ASAS were performed both before and after the 1994 BOREAS field season. The spectral stability was also checked once in the middle of the field season using a portable helium neon laser. It has been determined that the spectral calibration results from 13-Oct-1994 are most appropriate for all 1994 and 1996 BOREAS data sets.

4.2.3 Other Calibration Information

None.

5. Data Acquisition Methods

The ASAS instrument is mounted on the underside of the platform aircraft fuselage with the sensor optics either slightly protruding into the slipstream or retracted into the fuselage pressure box, depending on the view angle. As the aircraft approaches the target site from a distance, the ASAS instrument is pointed forward-looking. A video camera bore-sighted with the ASAS optical head relays a picture to an onboard monitor screen at the ASAS operators' station. This enables the operator to identify the site and continue tracking it through a sequence of view angles as the aircraft proceeds on a flight line over the site. When the site comes into view on the forward point, the operator begins the data acquisition. The sequence is timed such that the view is at nadir when the aircraft is directly over the site, and aft-looking views are taken after passing the site. Determining which views are forwardscatter or backscatter requires examination of the aircraft heading and the solar azimuth angle, given in the ASAS ASCII header.

During the 1994 BOREAS missions, data were acquired as follows: Flux Towers - view azimuths parallel, perpendicular and oblique to the solar principal plane; multiple view zenith angles. Transect or Modeling Sub-Area Mapping Grids - nadir view zenith angle. During the 1996 BOREAS missions, data were acquired as follows: Flux Towers - view azimuths parallel, oblique, and occasionally perpendicular to the solar principal plane; multiple view zenith angles. Transect - nadir view zenith angle. Data over targets of opportunity in 1994 and 1996 usually were acquired only in the solar principal plane and may be multiangle or nadir data.

As the platform aircraft flies forward, each row of 512 detector bins is electronically scanned to generate 62 spectral channels of digital image data in a push-broom mode. The signals generated by the CCD detectors are sampled at a rate of 38 frame lines per second to produce the along-track dimension of the imagery (image lines). The sampled signal from each detector is digitized to 12 bits and the digital data are stored on a high-density S-VHS format tape using a buffered VLDS data recorder.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

The ASAS operators do not make extensive notes about field conditions during missions. ASAS usually is not flown if atmospheric conditions are not sufficiently clear. If sky conditions are satisfied, it is up to Principal Investigators to decide if field conditions are appropriate for data acquisition. Any observations noted by ASAS operators are made at altitude, and if considered pertinent to the data, are included in the ASAS header COMMENTS field.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The 1994 BOREAS sites acquired by ASAS consisted of six flux tower sites in the SSA and five flux tower sites in the NSA. In addition, data were acquired over a calibration target in the SSA. In 1996, in addition to the flux towers, data were acquired over an "agricultural/open" area south of the SSA_FEN and Namekus Lake during the winter field campaign. ASAS BOREAS imagery of the flux tower sites (at a NADIR view) cover areas that are typically about 1.5-2.0 km wide and up to several km long.

Nadir data over the auxiliary sites may be available in the Modeling Sub-Area Mapping Grid and Transect Nadir data sets. Routine processing of the Modeling Sub-Area Grid and Transect data sets is not planned at this time. After flux tower data sets have been provided to the BOREAS Information System (BORIS), the Sub-Area and Transect data may be processed if there are requests from the user community for these data.

The North American Datum of 1983 (NAD83) corner coordinates of the SSA are:

```
              Latitude      Longitude
              --------      ---------
Northwest     54.321 N      106.228 W
Northeast     54.225 N      104.237 W
Southwest     53.515 N      106.321 W
Southeast     53.420 N      104.368 W
```

The NAD83 corner coordinates of the NSA are:

```
              Latitude      Longitude
              --------      ---------
Northwest     56.249 N       98.825 W
Northeast     56.083 N       97.234 W
Southwest     55.542 N       99.045 W
Southeast     55.379 N       97.489 W
```

```
     Site                Latitude      Longitude
----------------         --------      ---------
SSA_FEN                  53.801 N      104.619 W
SSA_OA                   53.629 N      106.198 W
SSA_OBS                  53.988 N      105.119 W
SSA_OJP                  53.916 N      104.690 W
SSA_YJP                  53.876 N      104.647 W
```

SSA_YA	53.655 N	105.322 W	
SSA_AVIRIS_CAL	53.24 N	105.69 W	
SSA_OPEN_AG	53.57 N	104.78 W	Denoted as SSA_AGR or SSA_AG
SSA_NAMEKUS_LAKE	53.83 N	106.04 W	Denoted as SSA_NAK
NSA_ATE (NSA_OA)	55.887 N	098.675 W	Could be denoted as NSA_OA
NSA_FEN	55.915 N	098.421 W	
NSA_OBS	55.880 N	098.481 W	
NSA_OJP	55.928 N	098.624 W	
NSA_YJP	55.896 N	098.287 W	

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

Across-track direction:

ASAS spatial resolution in the x-direction is a function of the across-track field of view, view angle, and the altitude of the platform aircraft. The across-track pixel size (in meters) is given in the header of each ASAS image. Across-track pixels do not overlap.

Some examples of across-track spatial resolutions:

- At a nadir view angle and an altitude of 5000 m above ground level (AGL), the full-scene across-track field of view is 1.7 km, and the individual pixel size (across-track) is 3.3 m.
- At a 60° off-nadir view angle and an altitude of 5000 m AGL, the full-scene across-track field of view is 3.4 km, and the individual pixel size (across-track) is 6.6 m.

Along-track direction:

The along-track spatial resolution of an ASAS image pixel is more complicated. Two aspects are involved:

- The ground footprint size.
- The distance over which the footprint is "smeared" as the aircraft advances.

The ground footprint is determined by the along-track IFOV in conjunction with the view angle and aircraft altitude and attitude (mainly pitch). The IFOV is described in Section 5.1.5.

The radiance measurement recorded for a given pixel is representative of the ground area observed as the pixel footprint moves forward by the ground distance of one frame (ASAS is a push-broom scanner). The ground footprint will be larger for an off-nadir view angle than for a nadir view. For example, at an altitude of 5,000 meters, the footprint in the along-track direction is approximately 8 meters at a view angle of 60° versus 2 meters for nadir.

Regardless of how large or small the footprint is, the ground distance over which a pixel is "smeared" is determined by the data collection rate, which is a function of the aircraft speed, divided by the frame rate. Given a fixed frame rate during the BOREAS data missions of 38 frames per second and a typical aircraft ground speed of 220 knots, the spacing or smear distance between adjacent frames is approximately 3 meters. Thus, an along-track footprint of 2 meters at nadir (using the example above) would be smeared over a distance of 3 meters. This results in a 2 meter overlap and a center-to-center distance of 3 meters between pixels of adjacent frames. The effective resolution is therefore limited by the smearing.

All ASAS data sets are oversampled in the along-track direction. This means that each image line somewhat overlaps the previous line, making the images appear more elongated than in reality. Images are not oversampled in the across-track direction. This frame or line overlap is not corrected for during operational ground processing.

An along-track (y-direction) pixel size in meters is given in the header of each ASAS image file. This number is the aircraft speed divided by the frame rate, which equals the smear distance or non-overlap portion of each pixel in the y-direction. The y-direction pixel size times the number of lines is approximately equal to the total ground distance imaged by ASAS for a given view angle.

Some example along-track pixel sizes during BOREAS:

- 3.1 m (ground speed = 230 knots)
- 3.2 m (ground speed = 235 knots)

NOTE: BOREAS ASAS data were acquired at altitudes of approximately 4600-5800 m above ground for multiangle flux tower data, and 7000-8000 m above ground for nadir transect data.

7.1.4 Projection

The ASAS data are stored in the spatial frame in which they were collected. The digital image data are not resampled in order to retain the radiometric integrity of each pixel. Consequently, the image data are neither registered to a geographic projection nor are the image data view angle-corrected. The digital images retain geometric distortion resulting from the off-nadir tilting, the rectangular ground sample dimensions, and the variation in aircraft roll, pitch, and yaw during data acquisition. Resampling and registration are left to the discretion of the investigators analyzing ASAS data.

7.1.5 Grid Description

The ASAS data are stored in the spatial frame in which they were collected.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

```
   Date                   Sites
-----------    ---------------------------------------------------------
19-Apr-1994    SSA_OBS, SSA_OA, SSA_OJP
20-Apr-1994    NSA_OBS, NSA_OJP, NSA_YJP, NSA_FEN

26-May-1994    SSA_AVIRIS_CAL
31-May-1994    SSA_OA, SSA_OJP
01-Jun-1994    SSA_YJP
06-Jun-1994    SSA_OBS, SSA_FEN, SSA_OJP
07-Jun-1994    NSA_OBS, NSA_OJP, NSA_YJP, NSA_FEN
08-Jun-1994    NSA_OA (NSA_ATE)

21-Jul-1994    SSA_OBS, SSA_OA, SSA_OJP, SSA_YJP, SSA_FEN
23-Jul-1994    SSA_YA, SSA_AVIRIS_CAL
24-Jul-1994    SSA_OJP, SSA_FEN, SSA_YA  3
04-Aug-1994    NSA_OBS, NSA_OJP  (smoke present)

06-Sep-1994    NSA_OA (NSA_ATE)
13-Sep-1994    SSA_OBS, SSA_OJP, SSA_YJP, SSA_FEN
16-Sep-1994    SSA_OA, SSA_AVIRIS_CAL
17-Sep-1994    NSA_OBS, NSA_OA (NSA_ATE), NSA_OJP, NSA_YJP, NSA_FEN

04-Mar-1996    SSA_OA, SSA_OBS
11-Mar-1996    SSA_OA, SSA_OBS, SSA_YJP, SSA_OJP, SSA_AG, SSA_NAK
12-Mar-1996    SSA_AG, SSA_OJP, SSA_YJP, SSA_OBS
18_Jul-1996    NSA_OA (NSA_ATE), NSA_OJP, NSA_FEN, NSA_OBS, NSA_YJP
20-Jul-1996    SSA_OBS, SSA_OJP, SSA_FEN, SSA_OA
24-Jul-1996    NSA_OJP, NSA_OA (NSA_ATE), NSA_FEN
29-Jul-1996    SSA_OBS, SSA_OJP
30-Jul-1996    SSA_YJP, SSA_OJP, SSA_YA, SSA_OBS
```

7.2.2 Temporal Coverage Map

See Section 7.2.1.

7.2.3 Temporal Resolution

ASAS site passes may vary slightly in time duration, depending on the length of the flight line and the aircraft speed. Typically one multiangle pass over a site has a duration of about 5 minutes.

7.3 Data Characteristics

Due to differences in the information that is available for ASAS data collected in 1994 and 1996, the inventory tables given on the CD-ROM contain different sets of parameters. The following sections describe the actual image data and the inventory files provided on the CD-ROM series.

7.3.1 Parameter/Variable

Image files:

```
Scaled at-sensor radiance: Values are stored in image files as digital
                           numbers (DNs). To obtain radiance in units
                           described below (7.3.3) divide DN values by a
                           band-specific radiometric resolution factor.
```

The parameters contained in the inventory files on the CD-ROM are:

```
         Column Name
------------------------------
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
PLATFORM_ALTITUDE
ASAS_VIEW_ANG
ASAS_SCAN_RATE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
C130_MISSION_ID  (missing from the 1996 data)
C130_LINE_NUM    (missing from the 1996 data)
C130_RUN_NUM     (missing from the 1996 data)
C130_SITE        (missing from the 1996 data)
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
CRTFCN_CODE
```

7.3.2 Variable Description/Definition

Image files:

At-sensor radiance (after division by spectral radiometric resolution factor)	: The derived radiant energy incident on the sensor aperture at the time of data collection in the specific ASAS wavelength regions.

The descriptions of the parameters contained in the inventory files on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
PLATFORM	The object (e.g., satellite, aircraft, tower, person) that supported the instrument.
INSTRUMENT	The name of the device used to make the measurements.
NUM_BANDS	The number of spectral bands in the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.
ASAS_VIEW_ANG	The list of view angles (in degrees) acquired by the ASAS instrument on this site pass.
ASAS_SCAN_RATE	The ASAS sensor scans in a push-broom fashion one row (frame) at a time. In the image header this is referred to as the frame rate and is the number of rows of image data captured per second.
MIN_SOLAR_ZEN_ANG	The minimum angle from the surface normal (straight up) to the sun during the data collection.
MAX_SOLAR_ZEN_ANG	The maximum angle from the surface normal (straight up) to the sun during the data collection.
MIN_SOLAR_AZ_ANG	The minimum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
MAX_SOLAR_AZ_ANG	The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
C130_MISSION_ID	The mission identifier assigned to the C130 mission in the form of YY-DDD-FF where YY is the last two digits of the fiscal year, DDD is the deployment number for "official" C130 missions and is day of year for non-"official" C130 missions (i.e., no site coverage), and FF is the flight number within the given deployment (00 is given for non-"official" C130 missions). An example would be 94-006-04.

Note that the C130_MISSION_ID, C130_LINE_NUM, C130_RUN_NUM, and C130_SITE columns are missing from the 1996 data. The mission information in 1994 was provided by personnel in the NASA Earth Resources Aircraft Program at NASA/ARC. In 1996, the C130 aircraft was provided by the NASA/WFF, which did not create this mission information. The reference to "non-official" C130 missions above applies primarily to sun photometer data from the C130 platform in 1994 (RSS-12) where data was collected on the tarmac and possibly within flight, but the "official" C130 mission was aborted before or slightly after takeoff.

C130_LINE_NUM	The number of the C130 line in its flights over the BOREAS area as given in the flight logs. Zero values are given for non-"official" C130 missions and for data between C130 sites or lines.
C130_RUN_NUM	The number of the C130 run in its flights over the BOREAS area as given in the flight logs. Zero value is given for non-"official" C130 missions and data between C130 sites, lines or runs.
C130_SITE	The C130 site designator as given in the flight logs. PRE is used for data taken from the airport to the first "official" C130 site, BTW is used for data taken between two "official" C130 sites, DSC is used for data taken after the last "official" C130 site, TRN is used for transect data, and YTH and YPA are used for data taken at the YTH and YPA airports (aircraft never left the ground).
NW_LATITUDE	The NAD83 based latitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NW_LONGITUDE	The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NE_LATITUDE	The NAD83 based latitude coordinate of the northeast corner of the minimum bounding rectangle for the data.
NE_LONGITUDE	The NAD83 based longitude coordinate of the northeast corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.
SW_LONGITUDE	The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.
SE_LATITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).

7.3.3 Unit of Measurement

Image files:

DN/spectral radiometric resolution factor :	At-sensor radiance in units of mW/(cm^2 * sr * µm). The band-specific radiometric resolution factors are stored in each ASAS image header. To obtain units of W/(m^2 * sr * µm), multiply mW/(cm^2 * sr * µm) by 10.

The measurement units for the parameters contained in the inventory files on the CD-ROM are:

Column Name	Units	
SPATIAL_COVERAGE	[none]	
DATE_OBS	[DD-MON-YY]	
START_TIME	[HHMM GMT]	
END_TIME	[HHMM GMT]	
PLATFORM	[none]	
INSTRUMENT	[none]	
NUM_BANDS	[counts]	
PLATFORM_ALTITUDE	[meters]	
ASAS_VIEW_ANG	[none]	
ASAS_SCAN_RATE	[unitless]	
MIN_SOLAR_ZEN_ANG	[degrees]	
MAX_SOLAR_ZEN_ANG	[degrees]	
MIN_SOLAR_AZ_ANG	[degrees]	
MAX_SOLAR_AZ_ANG	[degrees]	
C130_MISSION_ID	[none]	(Missing from the 1996 data)
C130_LINE_NUM	[none]	(Missing from the 1996 data)
C130_RUN_NUM	[none]	(Missing from the 1996 data)
C130_SITE	[none]	(Missing from the 1996 data)
NW_LATITUDE	[degrees]	
NW_LONGITUDE	[degrees]	
NE_LATITUDE	[degrees]	
NE_LONGITUDE	[degrees]	
SW_LATITUDE	[degrees]	
SW_LONGITUDE	[degrees]	
SE_LATITUDE	[degrees]	
SE_LONGITUDE	[degrees]	
CRTFCN_CODE	[none]	

7.3.4 Data Source

Image files: At-sensor radiance is derived from calibrating the acquired ASAS image counts. The sources of the parameter values contained in the inventory files on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Assigned by BORIS]
DATE_OBS	[ASAS image header]
START_TIME	[ASAS image header]
END_TIME	[ASAS image header]
PLATFORM	[ASAS image header]
INSTRUMENT	[Assigned by BORIS]
NUM_BANDS	[ASAS image header]
PLATFORM_ALTITUDE	[ASAS image header]
ASAS_VIEW_ANG	[ASAS image header]

ASAS_SCAN_RATE	[ASAS image header]	
MIN_SOLAR_ZEN_ANG	[ASAS image header]	
MAX_SOLAR_ZEN_ANG	[ASAS image header]	
MIN_SOLAR_AZ_ANG	[ASAS image header]	
MAX_SOLAR_AZ_ANG	[ASAS image header]	
C130_MISSION_ID	[ASAS image header]	(Missing from the 1996 data)
C130_LINE_NUM	[ASAS image header]	(Missing from the 1996 data)
C130_RUN_NUM	[ASAS image header]	(Missing from the 1996 data)
C130_SITE	[ASAS image header]	(Missing from the 1996 data)
NW_LATITUDE	[Computed by BORIS]	
NW_LONGITUDE	[Computed by BORIS]	
NE_LATITUDE	[Computed by BORIS]	
NE_LONGITUDE	[Computed by BORIS]	
SW_LATITUDE	[Computed by BORIS]	
SW_LONGITUDE	[Computed by BORIS]	
SE_LATITUDE	[Computed by BORIS]	
SE_LONGITUDE	[Computed by BORIS]	
CRTFCN_CODE	[Assigned by BORIS]	

7.3.5 Data Range

Image files: Scaled at-sensor radiance (DNs) - 12-bit data range (0-4095) stored in 16-bit integers
The range of parameter values contained in the inventory file for the 1994 data on the CD-ROM is:

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	19-APR-94	17-SEP-94	None	None	None	None
START_TIME	1527	2112	None	None	None	None
END_TIME	1529	2115	None	None	None	None
PLATFORM	C130	C130	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	62	62	None	None	None	None
PLATFORM_ALTITUDE	4633	5791.2	None	None	None	None
ASAS_VIEW_ANG	N/A	N/A	None	None	None	None
ASAS_SCAN_RATE	38	38	None	None	None	None
MIN_SOLAR_ZEN_ANG	33.5	61.1	None	None	None	None
MAX_SOLAR_ZEN_ANG	33.5	61.4	None	None	None	None
MIN_SOLAR_AZ_ANG	108.4	228.6	None	None	None	None
MAX_SOLAR_AZ_ANG	109.1	229.6	None	None	None	None
C130_MISSION_ID	94-004-10	94-009-09	None	None	None	None
C130_LINE_NUM	101	703	None	None	None	None
C130_RUN_NUM	1	3	None	None	None	None
C130_SITE	429	431	None	None	None	None
NW_LATITUDE	53.24665	55.94083	None	None	None	None
NW_LONGITUDE	-106.21453	-98.29598	None	None	None	None
NE_LATITUDE	53.24525	55.93712	None	None	None	None
NE_LONGITUDE	-106.18277	-98.25648	None	None	None	None
SW_LATITUDE	53.22982	55.92403	None	None	None	None
SW_LONGITUDE	-106.21694	-98.3016	None	None	None	None
SE_LATITUDE	53.22822	55.92094	None	None	None	None
SE_LONGITUDE	-106.18487	-98.26697	None	None	None	None
CRTFCN_CODE	CPI-PRE	CPI-PRE	None	None	None	None

```
-------------------------------------------------------------------------------
Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data.  This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits.  This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the analysis personnel determined
                      that the parameter value was below the detection
                      limit of the instrumentation.
Data Not Cllctd    -- This value indicates that no attempt was made to
                      determine the parameter value.  This usually
                      indicates that BORIS combined several similar but
                      not identical data sets into the same data base table
                      but this particular science team did not
                      measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
-------------------------------------------------------------------------------
```

7.4 Sample Data Record

The sample data record is not provided nor applicable for image data. The following are wrapped versions of sample records from the 1994 inventory file on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
PLATFORM_ALTITUDE,ASAS_VIEW_ANG,ASAS_SCAN_RATE,MIN_SOLAR_ZEN_ANG,
MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,MAX_SOLAR_AZ_ANG,C130_MISSION_ID,
C130_LINE_NUM,C130_RUN_NUM,C130_SITE,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,CRTFCN_CODE
'SSA-OBS',19-APR-94,1713,1715,'C130','ASAS',62,4633.0,
'60 45 26 15 0 -15 -26 -45-55',38,47.6,47.8,143.5,144.3,'94-004-10',101,1,
'429',53.99938,-105.13468,53.99769,-105.10065,53.97925,-105.13757,53.97755,
-105..10356,'CPI-PRE'
'SSA-OBS',19-APR-94,1724,1727,'C130','ASAS',62,4633.0,
'60 45 26 15 0 -15 -26 -45-55',38,46.6,46.8,147.3,148.1,'94-004-10',103,1,'429',
53.99613,-105.13056,53.99489,-105.10564,53.98204,-105.13259,53.9808,-105.10768,
'CPI-PRE'
```

The following are wrapped versions of sample records from the 1996 inventory file on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
PLATFORM_ALTITUDE,ASAS_VIEW_ANG,ASAS_SCAN_RATE,MIN_SOLAR_ZEN_ANG,
MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,MAX_SOLAR_AZ_ANG,NW_LATITUDE,NW_LONGITUDE,
NE_LATITUDE,NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,
CRTFCN_CODE
'SSA-9OA',04-MAR-96,1754,1757,'C130','ASAS',62,4419.6,'60 45 26 0 -26 -45 -55',
38,62.0,62.2,156.8,157.5,53.64802,-106.21728,53.64626,-106.17425,53.61376,
-106.22125,53.612,-106.17826,'CPI-PRE'
'SSA-9OA',04-MAR-96,1832,1835,'C130','ASAS',62,4480.6,'60 45 26 0 -26 -45',
38,60.3,60.4,167.4,168.1,53.64069,-106.21943,53.63882,-10 6.17382,53.6212,
-106.22169,53.61933,-106.1761,'CPI-PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest obtainable unit of data is a complete ASAS site pass, which consists of 5 to 10 images per site at multiple view angles acquired by the ASAS instrument as it approaches and passes a given target.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

The CD-ROM inventory listing file consists of numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

One level-1b ASAS image product consists of a series of files in which the first file is an ASCII header file followed by a series of image data files. The ASCII header file consists of 80-byte ASCII character records that describe the whole image product and give general acquisition information.

Each image file consists of a series of logical records that are 8,192 bytes in length. The first record contains ASCII header information in a format described below. Within the physical header record, the logical header records are delimited with a new line character, enabling recognition of the end of each header record component. Subsequent file records of 8,192 bytes contain eight logical image records of 1,024 bytes each. The 1,024 bytes contain 512 two-byte (16-bit) integer pixel values that are scaled at-sensor radiances. The byte ordering is high-order byte first. The image lines are ordered band-sequentially; that is, all lines for band 1, followed by all lines for band 2, and so forth for all 62 bands. The number of lines per view angle may vary. The total number of records per file equals the number of lines in the image times the number of bands (62) plus NUM_HDR_BYTES listed in the header. There are no end-of-record or other special characters between logical records.

A sample ASAS ASCII header record appears below:

```
EXAMPLE BOREAS ASAS IMAGE HEADER FORMAT (with some explanations added)

ASAS2_HDR_VERSION: 2.83
NUM_HDR_BYTES:8192
FILE_NAME: tilt_+26.cal
TYPE_OF_DATA: IN-FLIGHT
#
#DATE INFORMATION
#
LOCAL_DATE: 26MAY94
```

```
START_DATE_GMT: 26MAY94 17:26:55
STOP_DATE_GMT: 26MAY94 17:27:08
SOLAR_AZIMUTH(deg):  143.7
SOLAR_ZENITH(deg):   38.3
#
#IMAGE SIZE INFORMATION
#
NUM_LINES:  512  (can vary)
NUM_PIXELS:  512
NUM_BANDS:  62
DATA_TYPE: UNSIGNED INTEGER*2
DATA_ORDERING: SUN UNIX  (Based on SunOs 4.1.3)
FORMAT: BAND_SEQUENTIAL
STARTING_LINE: 31268  (From beginning of Level 0 product)
STARTING_PIXEL:1
ACROSS_TRACK_PIXEL_SIZE(m): 4.1
ALONG_TRACK_PIXEL_SIZE(m): 3.2   (non-overlap portion)
IMAGE_DESCRIPTION:
#
#GEOGRAPHIC LOCATION INFORMATION
#
GLOBAL_REGION: North America
COUNTRY: Canada
POLITICAL_SUBDIVISION: Saskatchewan
GEOGRAPHICAL_REGION: Boreal forest
LAT_CENTER:  53.24000 (refers to target site, not image center)
LON_CENTER: -105.69000  (refers to target site, not image center)
RADIUS(km):  1.346
#
#MISSION INFORMATION
#
PROJECT: BOREAS
FLIGHT_PROJ_NUM: 43002
MISSION_NUM: 406
FLIGHT_NUM: 02
LINE_NUM: 601
RUN_NUM:  2
SITE_NUM:   6  (C-130 site designation only)
SITE: SSA AVCAL
SITE_DESCRIPTOR: AVIRIS CAL SITE
INVESTIGATOR: Dr. J. Irons
#
#COMMENTS
#
Perpendicular  (relation to solar principal plane)
#
#INSTRUMENT INFORMATION
#
TILT_ANGLE: 26  (angle at which sensor is pointed, in degrees)
FRAME_RATE: 38  (frames per second)
#
#AIRCRAFT INFORMATION
FLIGHT_FACILITY: NASA/AMES
PLATFORM: NASA C-130
```

```
ALTITUDE_AGL(m):  5608.3  (AGL = above ground level)
GROUND_SPEED(knots):  240
HEADING(deg): 322
#
#PROCESSING INFORMATION
#
PROCESSING_DATE: 26JUN95
PROCESSING_FACILITY: NASA GSFC
PROCESSING_LEVEL: 1B   (EOS designation)
PROCESSING_HISTORY: dd swapcomp decom borcal energizer hdrstats  (proc programs)
#
#CALIBRATION INFORMATION
#
SPECTRAL_CAL_DATE: 13OCT94
RAD_CAL_DATE: 02AUG94
RAD_CAL_SOURCE: Hemisphere, Integrating
SOURCE_CAL_DATE: 31JUL94
S/N_FORMULA_ORDER: 2  (See Section 5.2 A for discussion)
S/N_FORMULA_COEFFICIENTS   (of S/N ratios)
C0   1.707e+00
C1   2.905e-01
C2  -2.867e-05

S/N_DESCRIPTION: S/N = C0 + C1*DN + C2*DN^2  (using coefficients above) or S/N =
C0 + C1*Radiance + C2*Radiance^2 where C0, C1, and C2 are given in the table
below.   (This second equation using radiance should read S/N = S/N(C0) +
S/N(C1)*Radiance + S/N(C2)*Radiance^2 where S/N(C0), S/N(C1), and S/N(C2) are
given in the table below.)

UNITS: DN/RAD_RES_FACT = mW cm-2 sr-1 µm-1   (RAD_MEAN is in these units)
```

BAND	CENTER	FWHM	RAD_RES_ FACT	RAD_ MEAN	S/N_ MEAN	S/N(C0)	S/N(C1)	S/N(C2)
1	404.3	9.5	41	0.24	4	1.707e+00	1.191e+01	-4.819e-02
2	413.7	9.5	49	0.42	10	1.707e+00	1.423e+01	-6.884e-02
3	423.2	9.5	59	0.75	21	1.707e+00	1.714e+01	-9.980e-02
4	432.4	10.0	70	1.03	35	1.707e+00	2.033e+01	-1.405e-01
5	441.7	10.0	79	1.38	54	1.707e+00	2.295e+01	-1.789e-01
6	451.4	10.0	94	1.68	80	1.707e+00	2.731e+01	-2.533e-01
7	460.9	10.0	115	1.85	110	1.707e+00	3.341e+01	-3.792e-01
.								
.	(channels 8 through 58 will be here; S/N ratios highest in middle channels)							
.								
59	991.5	10.5	13	3.36	14	1.707e+00	3.776e+00	-4.845e-03
60	1001.9	10.5	9	3.37	10	1.707e+00	2.614e+00	-2.322e-03
61	1012.2	10.5	6	3.36	8	1.707e+00	1.743e+00	-1.032e-03
62	1022.7	10.5	3	3.48	5	1.707e+00	8.715e-01	-2.580e-04

```
#
#END_HDR   (Marks end of header text)
```

To determine forward scatter and backward scatter, compare aircraft heading to solar azimuth angle. If the plane was heading into the sun, forward (positive) points are forward scatter and aft (negative) points are backscatter. If the plane was heading away from the sun, forward points are backscatter and aft points are forward scatter.

The terms "tilt," "look," "point," or "view" angles generally are used interchangeably when referring to the ASAS view zenith angles, however the actual view zenith angle may vary from the angle at which the sensor is pointed due to an across-track angular component to the view zenith angle. This across-track angular component is largest at a nadir-pointing angle, and relatively insignificant at far off-nadir pointing angles. For the BOREAS data collection flights, ASAS imaged most study sites at 8 different tilt angles: +70°, +60°, +45°, +26°, nadir, -26°, -45°, and -55°. Areas in the imagery nearest the center detectors will have view zenith angles the same as the tilt angle, but areas at the edges of the array (far left and far right of a line) may have a different view zenith angle. The variation by tilt angle is given below:

TILT_ANGLE (fore and/or aft)	VIEW_ZEN_ANGLE (image center)	VIEW_ZEN_ANGLE (image edges)
70°	70.0°	70.2°
60°	60.0°	60.4°
55°	55.0°	55.5°
45°	45.0°	45.7°
26°	26.0°	27.5°
00°	0.0°	9.4°

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the ASCII header file for each image is stored as ASCII text; however, the binary image files have been compressed with the Gzip compression program (file name *.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (-d option) or gunzip. Gzip is available from many websites (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

Not applicable.

9.1.1 Derivation Techniques and Algorithms

Not applicable.

9.2 Data Processing Sequence

9.2.1 Processing Steps

For any given ASAS data set, the processing programs used to generate the data are listed in the ASAS header. In general, operational processing of 1994 data required six primary steps and operational processing of 1996 data required four primary steps. The all-inclusive list of programs is as follows, and these steps are described below: dd, swapcomp, decom, borcal, energizer, and hdrstats

ASAS measurements are stored on high-density S-VHS format tape using a Metrum buffered VLDS data recorder. The raw data are transferred to magnetic disk and 8-mm tape using a VLDS unit interfaced to a Unix workstation. These data consist of continual streams of frames in which each frame contains the combined image data for all 62 input channels and 2 smear data channels plus header and navigational information (if available) for a single image line. The data transfer process involves the Unix "dd" utility for reading the raw data and a program developed in-house called "swapcomp" for swapping and complementing the bytes of each 16-bit pixel where byte-swapping is necessary. Byte swapping was not needed for 1996 data.

Decommutating a single band of data encompassing all view angles creates a quicklook image for each site pass. Line coordinates of each view angle subset are manually selected, omitting areas of instrument "slew" and noncoverage of the site.

Next, all bands of each view angle subset in the site pass are decommutated. Each line of data is extracted and written to disk in band-sequential format. Each view angle subset is stored in a separate file with an ASCII header automatically populated with entries retrieved from an online database containing information about the specific project and sites.

At this point, image files consist of a series of logical records 1,024 bytes in length. The first several records store the header information. Subsequent records contain band-sequential integer*2 data. Each record represents 512 pixels.

Radiometric calibration is performed next using the in-house program "borcal." It applies the calibration gains derived from the selected radiometric calibration source (usually the integrating hemisphere) lamp data to each pixel. The output format is identical to the input format except that the 2 smear bands are removed. The calibration procedure is described in Section 4.2.

The next processing step for BOREAS ASAS data is correction of low-energy frames resulting from an array signal readout problem, for data affected by this occurrence. Section 4.2.1 discusses this problem. The program "energizer" attempts to correct the affected frames. Data are parsed four separate times to determine which frames fit the criteria for reduced energy or signal levels caused by the timing problem. The first pass involves the profiling of total energy versus frame, smoothing the profile to remove high and low frequency noise, and flagging of suspect frames using a mean value threshold. Subsequent passes attempt to refine the list of suspect frames based on the expected frequency. For most of the BOREAS 1994 data, the frequency of low-energy lines is every 6-7 frames. After the suspect frames are identified, they are multiplied by a corrective-weighting factor determined from the calibration data. Data acquired in 1996 did not contain low-energy frames.

The last operational processing step is calculation of the mean scene radiance levels for all bands of each view angle image in a site pass. The in-house "hdrstats" program computes the mean radiances [in $mW/(cm^2 * sr * \mu m)$] and stores them in the ASCII header of each image.

BORIS personnel processed the ASAS images by: Using developed software to extract information from the image header and data files for logging into the relational data base Selecting random images for visual review on a computer screen, Copying the ASCII and compressing the binary image files for use on the CD-ROM set.

9.2.2 Processing Changes

For the most part, most of the processing steps outlined in Section 9.2.1 apply to all 1994 and 1996 BOREAS data sets. However, there may be some inter-IFC differences in the data characteristics:

The data acquired for each IFC may have a specific set of calibration gains, radiometric resolution factors, and S/N ratios, depending on which calibration data were used.

The frequency of occurrence for the low-energy frame striping was every 6-7 lines for all 1994 IFCs except for SSA FFC-T data, where the frequency was approximately 29-30 lines. Low-energy frames did not occur in 1996 data sets.

For 1994 IFCs 1,2, 3, and all 1996 IFCs, data were acquired at the following eight view angles: +70°, +60°, +45°, +26°, nadir, -26°, -45°, and -55°. For the 1994 FFC-T, +15° and -15° view angles were included in the sequence. These angles describe the view angles that were attempted but not necessarily achieved in all cases.

S/N ratio calculations for 1996 data used third order polynomial equations instead of second-order polynomials.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

See Section 9.2.

9.3.2 Calculated Variables

Radiance.

9.4 Graphs and Plots

Not applicable.

10. Errors

10.1 Sources of Error

Potential sources of uncertainty associated with ASAS spectral radiance include the following factors: spectral radiance from the integrating hemisphere; spectral radiance from the portable hemisphere; transfer of spectral radiance to ASAS detector elements; and spectral calibration of the ASAS detector elements. Other factors such as polarization sensitivity, signal cross-talk between detectors, and stray light may contribute to the uncertainty, but these factors have not been evaluated.

10.2 Quality Assessment

10.2.1 Data Validation by Source

During processing, frequency histograms of selected channels for each view angle are plotted and examined manually for anomalies. Images are also displayed and visually analyzed for target coverage, data dropouts, saturation, and other potential problems.

10.2.2 Confidence Level/Accuracy Judgment

The uncertainty associated with ASAS spectral radiance values is approximately 6%. This number is the root-sum-square of the uncertainties contributed by the following factors: spectral radiance from the integrating hemisphere (5% uncertainty); transfer of spectral radiance to ASAS detector elements (2% uncertainty); and spectral calibration of the ASAS detector elements (1% uncertainty). The uncertainty associated with the radiance of the portable hemisphere has not been determined, however it is probably similar to that of the integrating hemisphere. Other factors such as polarization sensitivity, signal cross-talk between detectors, and stray light may contribute to the uncertainty, but these factors have not been evaluated.

10.2.3 Measurement Error for Parameters

The uncertainty associated with ASAS spectral radiance values is approximately 6%.

10.2.4 Additional Quality Assessments

Spectral response curves for selected training areas are plotted and examined for known atmospheric absorption features. These plots are also compared to similar measurements made by other instruments, if data are available.

10.2.5 Data Verification by Data Center

BOREAS Information System staff developed software to read, verify, and extract information contained in the ASAS image header files. This information was reviewed and loaded into the relational data base. In addition, several random images were reviewed visually on a video display. No problems were found during the reviews.

11. Notes

11.1 Limitations of the Data

ASAS data acquired over the SSA calibration target (a soil field) were atmospherically corrected and compared to ground measurements. The results show ASAS to agree well with the ground observations between 490 and 870 nm. Below 490 nm and above 870 nm, the ASAS response falls below the expected level.

Though a specific sequence of view angles from +70° to -55° was attempted for each flight line over the flux tower sites, not all look angles were achieved every time. (Often the 70° off-nadir view missed the site or contained too much distortion for inclusion in the data set.)

The data are not geo-rectified, geo-registered, or atmospherically corrected.

11.2 Known Problems with the Data

Image Data:

- Several of the 31,744 detectors in the ASAS array are inoperable; these will produce vertical striping in the spectral channel in which they occur.
- The correction for low-energy frames (lines) due to the array timing problem may not be successful in all data sets and some frames (lines) may exhibit nonbright horizontal striping.
- ASAS data acquired over the SSA calibration target (a soil field) were atmospherically corrected and compared to ground measurements. The results show ASAS to agree very well with the ground observations between 490 and 870 nm. Below 490 nm and above 870 nm, the ASAS response falls below the expected level.
- Though a specific sequence of view angles from +70° to -55° was attempted for each flight line over the flux tower sites, not all look angles were achieved every time. (Often the 70° off-nadir view missed the site or contained too much distortion for inclusion in the data set.)

Header Information:

- The altitude, heading, and ground speed parameters in the image headers originated from operator flight logs and therefore may not be completely accurate. If such parameters are very important to the user, navigation data (taken by the C-130 crew), which are available from NASA ARC or BORIS for 1994 data sets, should independently corroborate them. Navigation data for 1996 summer flights may be available from SLICER staff at NASA GSFC.
- There is a known incorrect aircraft heading in one of the ASAS data sets: the heading for 7/21/94 L701R1 SSA_FEN should read 228° instead of 37°.
- Site elevations in the headers may show discrepancies among the same sites, and discrepancies with elevations listed in BORIS. Elevations retrieved from topographic maps were systematically lower than Global Positioning System (GPS) elevations listed in BORIS. The value listed in the ASAS header represents only an approximate elevation for the site and should not be interpreted as an exact, accurate value.
- A SOURCE_CAL_DATE of 00JUL01 should read 31JUL94.
- The column RAD_MEAN may be missing from some headers.
- S/N_MEANS of negative integers are invalid.
- The S/N_DESCRIPTION gives two equations:

$$S/N = C0 + C1*DN + C2*DN^2$$

(This equation uses digital numbers (DN) and the spectrally invariant coefficients listed above the equation as C0, C1, and C2)

$$S/N = C0 + C1*Radiance + C2*Radiance^2$$

where C0, C1, and C2 are given in the table below. This second equation using radiance should read

$$S/N = S/N(C0) + S/N(C1)*Radiance + S/N(C2)*Radiance^2$$

where S/N(C0), S/N(C1), and S/N(C2) are given in the table below.

S/N(C0), S/N(C1), and S/N(C2) are coefficients which vary spectrally and the designation S/N(C#) is just a descriptor or term to distinguish the spectrally variant coefficients listed in the table from the spectrally invariant ones listed above the table, i.e. it does not mean S/N multiplied by the coefficient.

11.3 Usage Guidance

At present, the provided ASAS data are not geo-rectified or geo-located, nor are they corrected for atmospheric effects. Accurate accounting of atmospheric effects on the at-sensor radiance measurements is very important, since ASAS data acquisition involves observations through varying path lengths.

Users should view ASAS images thoroughly in all spectral bands of interest and select study areas carefully. Check the ASAS ASCII header for each data set's appropriate spectral radiometric resolution factors and S/N ratios. Use special caution working with channels below 490 nm or above 870 nm (see Section 11.1).

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None.

12. Application of the Data Set

These data can be used for a variety of studies, including:

- To characterize directional anisotropy of solar radiance reflected from terrestrial surfaces.
- To classify surface land cover types.
- To estimate hemispherical reflectance (albedo).
- To relate multiangle reflected radiances to biomass, species, stand structure, surface roughness, surface composition, Leaf Area Index (LAI), reflected Photosynthetically Active Radiation (PAR), absorbed PAR, and the fraction of absorbed PAR (fAPAR) (preferably done after removal of atmospheric effects). - As input to atmospheric correction algorithms. - To characterize atmospheric effects through different path lengths of atmosphere. - For Bidirectional Reflectance Distribution Function (BRDF) modeling and validation, after removal of atmospheric effects and geometric registration.

13. Future Modifications and Plans

Possible atmospheric correction and geographic registration of whole images and multiangle site passes for selected dates and sites (probably not the entire BOREAS ASAS archive).

14. Software

14.1 Software Description

Software for simple analysis of ASAS data is available through the ASAS World Wide Web site. The software is written in the Interactive Data Language (IDL) and requires a licensed copy of the commercial IDL package from Research Systems, Inc., in order to be run. Software procedures are provided for performing image input/output, retrieving the contents of image headers, displaying images, creating histograms, enhancing images, and generic image manipulation.

14.2 Software Access

The analysis software can be downloaded through a Web browser by accessing the following URL and clicking on "Processing and analysis software":

http://asas.gsfc.nasa.gov/doc/processing.html

Another link under the section "IDL software" can then be selected to view the list of available IDL programs. The "save" or "save as" features under the "File" menu in most web browsers may be used to download the programs as text files. For details on the use of each program, consult the embedded documentation at the top of each program.

Note: This software is the property of the U.S. Government. It is available without charge but is not intended for commercial redistribution. No guarantees are provided as to the accuracy or reliability of the code.

Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

15. Data Access

The level-1b ASAS imagery is available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

The BOREAS Level-1b ASAS data can be made available on 8-mm or Digital Archive Tape (DAT) media.

16.2 Film Products

Color aerial photographs and video records were made during data collection. The video record includes aircraft crew cabin intercom conversations and an audible tone that was initiated each time the sensor was triggered. The BOREAS data base contains an inventory of available BOREAS aircraft flight documentation, such as flight logs, videotapes, and photographs.

16.3 Other Products

A sample set of the ASAS IMAGES ARE AVAILABLE ON THE BOREAS CD-ROM SET. See Section 15 for information about how to obtain the other data that are available.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

ASAS INFORMATION VIA THE WORLD WIDE WEB http://asas.gsfc.nasa.gov/

Kovalick, W. and D. Graham. 1991. ASAS Programmer's Manual, Hughes STX, Code 923, NASA GSFC, Greenbelt, MD (in-house document).

Welch, T.A. 1984. A Technique for High Performance Data Compression. IEEE Computer, Vol. 17, No. 6, pp. 8-19.

17.2 Journal Articles and Study Reports

Many of the following articles describe data from the first generation CID array (prior to 1991). Radiometric resolution factors and spectral band centers differ among the various ASAS data sets.

Abuelgasim, A.A. and A. Strahler. 1994. Modeling bi-directional radiance measurements collected by the Advanced Solid-state Array Spectroradiometer (ASAS) over Oregon Transect conifer forests. Remote Sens. Environ. 47:261-275.

Abuelgasim, A.A., S. Gopal, J.R. Irons, and A.H. Strahler. 1996. Classification of ASAS multiangle and multispectral measurements using artificial neural networks. Remote Sens. Environ. 57:79-87.

Barnsley, M.J., P. Lewis, M. Sutherland, and J.-P. Muller. 1997. Estimating land surface albedo in the HAPEX-Sahel southern super-site: inversion of two BRDF models against multiple angle ASAS images. J. Hydrology 188-189:749-778.

Brown de Colstoun, E.C., C.L. Walthall, C.A. Russell, and J.R. Irons. 1995. Estimating the fraction of absorbed photosynthetically active radiation (fAPAR) at FIFE with airborne bi-directional spectral reflectance data. J. Geophys. Res. 100:25,523-25,535.

Deering, D.W., E.M. Middleton, J.R. Irons, B.L. Blad, E.A. Walter-Shea, C.J. Hays, C.L. Walthall, T.F. Eck, S.P. Ahmad, and B.P. Banerjee. 1992. Prairie grassland bi-directional reflectances measured by different instruments at the FIFE site. J. Geophys. Res. 97:18,887-18,903.

Guinness, E.A., R.A. Arvidson, J.R. Irons, and D.J. Harding. 1991. Surface scattering properties estimated from modeling airborne multiple emission angle reflectance data. Geophys. Res. Letters 18(11):2051-2054.

Hall, D.K., J.L. Foster, J.R. Irons, and P.W. Dabney. 1993. Airborne bi-directional radiances of snow covered surfaces in Montana, USA. Annals of Glaciology 17:35-40.

Irons, J.R., K.J. Ranson, D.L. Williams, R.R. Irish, and F.G. Huegel. 1991. An off-nadir pointing imaging spectroradiometer for terrestrial ecosystem studies. IEEE Trans. on Geoscience and Remote Sensing 29(1):66-74.

Johnson, L.F. 1994. Multiple view zenith angle observations of reflectance from ponderosa pine stands, Int. J. Remote Sens. 15:3859-3865.

Lawrence, W.T., D.L. Williams, K.J. Ranson, J.R. Irons, and C.L. Walthall. 1994. Comparative analysis of data acquired by three narrow-band airborne spectroradiometers over subboreal vegetation. Remote Sens. Environ. 47:204-215.

Moran, M.S., R.D. Jackson, T.R. Clarke, J. Qi, F. Cabot, K.J. Thome, and B.L. Markham. 1995. Reflectance factor retrieval from Landsat TM and SPOT HRV data for bright and dark targets. Remote Sens. Env. 52:218:230.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Qi, J., M.S. Moran, F. Cabot, and G. Dedieu. 1995. Normalization of sun/view angle effects using spectral albedo-based vegetation indices. Remote Sens. Env. 52:207-217.

Ranson, K.J., J.R. Irons, and D.L. Williams. 1994. Multispectral bi-directional reflectance of northern forest canopies with the Advanced Solid-state Array Spectroradiometer (ASAS). Remote Sens. Env. 47:276-289.

Russell, C.A., C.L. Walthall, J.R. Irons, and E.C. Brown de Colstoun. 1995. Comparison of airborne and surface spectral bi-directional reflectance factors, spectral hemispherical reflectance and spectral vegetation indices. J. Geophys. Res. 100:25,509-25,522.

Russell, C.A., J.R. Irons, and P.W. Dabney. 1997. Bidirectional reflectance of selected BOREAS sites from multiangle airborne data. J. Geophys. Res. 102(D24): 29,505-29,516.

Schaaf, C.B. and A.H. Strahler. 1994. Validation of bi-directional and hemispherical reflectances from a geometric-optical model using ASAS imagery and pyranometer measurements of a spruce forest. Remote Sens. Env. 49:138-144.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

AGL	- Above Ground Level
ARC	- Ames Research Center
ASAS	- Advanced Solid-state Array Spectroradiometer
ASCII	- American Standard Code for Information Interchange
AVIRIS	- Airborne Visible-Infrared Imaging Spectrometer
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
BRDF	- Bidirectional Reflectance Distribution Function
CASI	- Compact Airborne Spectrographic Imager
CCD	- Charge-Coupled Device
CD-ROM	- Compact Disk - Read-Only Memory
CID	- Charge-Injection Device
DAAC	- Distributed Active Archive Center
DAT	- Digital Archive Tape
DN	- Digital Number
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
fAPAR	- fraction of absorbed PAR
FFC-T	- Focused Field Campaign - Thaw
FFC-W	- Focused Field Campaign - Winter
FWHM	- Full-Width-at-Half-Maximum
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GPS	- Global Positioning System
GSFC	- Goddard Space Flight Center
HDR	- Header
IDL	- Interactive Data Language
IFC	- Intensive Field Campaign
IFOV	- Instantaneous Field-of-View
JSC	- Johnson Space Center
LAI	- Leaf Area Index
MAS	- MODIS Airborne Simulator
MISR	- Multi-angle Imaging SpectroRadiometer
MODIS	- Moderate Resolution Imaging Spectroradiometer
NAD83	- North American Datum of 1983
NASA	- National Aeronautics and Space Administration
NSA	- Northern Study Area
OA	- Old Aspen
OBS	- Old Black Spruce
OJP	- Old Jack Pine
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
PAR	- Photosynthetically Active Radiation
PARABOLA	- Portable Apparatus for the Rapid Acquisition of Bidirectional Observations of Land and Atmosphere
POLDER	- Polarization and Directionality of Earth's Reflectances
RSS	- Remote Sensing Science
S/N	- Signal-to-Noise
SIS	- Scanning Imaging Spectroradiometer
SLICER	- Scanning Lidar Imager of Canopies by Echo Recovery
SPP	- Solar Principal Plane
SSA	- Southern Study Area

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URL     - Uniform Resource Locator
VLDS    - Very Large Data Storage
WFF     - Wallops Flight Facility
YA      - Young Aspen
YJP     - Young Jack Pine
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13. ABSTRACT *(Maximum 200 words)*

The BOREAS RSS-2 team used the ASAS instrument, mounted on the NASA C-130 aircraft, to create at-sensor radiance images of various sites as a function of spectral wavelength, view geometry (combinations of view zenith angle, view azimuth angle, solar zenith angle, and solar azimuth angle), and altitude. The level-1b ASAS images of the BOREAS study areas were collected from April to September 1994 and March to July 1996.

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BOREAS, remote sensing science, ASAS instrument.

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